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The ISOLDE LEGO[®] robot: building interest in frontier research

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Abstract

An outreach programme centred around nuclear physics making use of a LEGO[®] Mindstorm[®] kit is presented. It consists of a presentation given by trained undergraduate students as science ambassadors followed by a workshop where the target audience programs the LEGO[®] Mindstorm[®] robots to familiarise themselves with the concepts in an interactive and exciting way. This programme has been coupled with the CERN-ISOLDE 50th anniversary and the launch of the CERN-MEDICIS facility in Geneva, Switzerland. The modular aspect of the programme readily allows its application to other topics.

 Supplementary material for this article is available [online](#)

1. The perception of nuclear physics in society

Nuclear science bears the stigma of its most visible outcomes of the 20th century, such as the bombing of Hiroshima and Nagasaki in 1945, or the explosion at the Chernobyl nuclear reactor in 1986. Behind those very visible events, many more activities have contributed to the bad reputation of nuclear research, such as the decades of environmental nuclear military testing or minor civil nuclear incidents around the globe. Altogether, the threat of nuclear disaster, added to

the impact of dramatic events, has swayed public opinion and convinced environmental movements to oppose all forms of nuclear activities.

Nuclear science is however different from nuclear engineering. The main focus is the deep understanding of the forces of nature through the study of the atomic nucleus. The nucleus itself carries more than 99.9% of the mass of the atom, while it only occupies 0.000 000 000 0001% of its volume. As matter, we are full of nothing, filled mostly with empty space. The nucleus is comprised of chargeless neutrons and positively-charged protons: how can these charged particles hold together against the Coulomb force at such close range? The answer lies with the strong force, named in part for holding against the Coulomb force, whose action is sufficient enough to overcome the repulsion of the protons from one another. And this question is only the beginning

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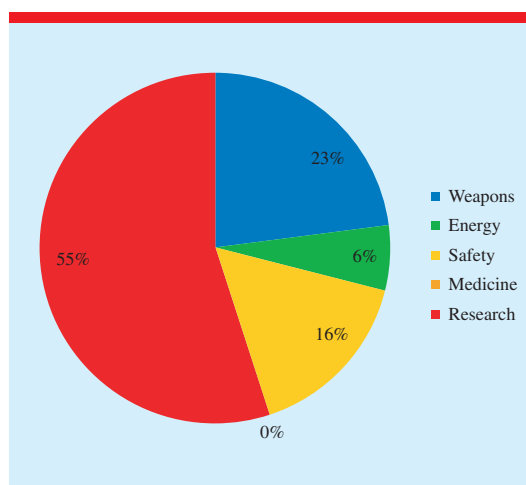


Figure 1. What does ‘nuclear physics’ mean to you? Break down of the answers from a sample of 31 students, aged 14–15, from the European School IV in Laeken, Brussels, Belgium. Note the lack of answers concerning nuclear medicine.

of how fascinating the nuclear medium can be in the study of fundamental properties.

If one now turns to the stars, those massive balls of gas that light our way and enthrall our fascination, one may wonder at how they are powered. The answer lies again in nuclear science: stars are giant fusion reactors, where nuclear energy is released continuously until there is no more energy left. At that point, a star collapses upon itself with gravity, until it blows out in a supernova explosion, during which many nuclear reactions occur, leading to the balance of elements as we know them in our solar system. While this story of the life cycle of a star takes here but a few lines, it occurs over billions of years, and involves countless nuclear reactions, not all of which are yet fully understood. Extensive work is therefore performed in many facilities worldwide in order to better understand how a star lives, breathes, and comes to pass, as well as all other forms of exotic galactic events that might be powered by the nuclear force.

Finally, but certainly not least of all, nuclear radiation has long been identified as a means of improving medical practices. During the First World War, Marie Curie had already identified many applications of nuclear and radiation physics, offering some of her personal radium sample to sterilize surgical instruments at the front line, as well as a portable radiography systems that could be used in those extreme conditions. Since then, great leaps have been made in the field of nuclear medicine,



Figure 2. Outside view of the CERN-MEDICIS and CERN-ISOLDE facilities with the Jura mountain range in the background. Reproduced with permission from Yury Gavrikov and CERN.

including SPECT and PET imaging, hadron therapy and targeted radiotherapy. Those fields are currently in expansion, as evidenced by the increase in proton therapy centers, e.g. in Manchester (UK), across the Netherlands, or in Leuven (Belgium).

But the question remains as to what people think of nuclear science. In a recent outreach project in Brussels (Belgium), a group of high school students were polled on their intuitive response to nuclear science. The results of the poll are shown in figure 1: more than half of those students were aware of the research interest of nuclear science, which is a testimony to the work that their teachers had performed previously. From the rest, a few were aware of safety concerns, some were worried about the military applications, while a small part expressed the importance it has for the generation of electricity. The most notable result of this poll was the complete absence of nuclear medicine amongst the results. This, in turn, shows where most of the effort is currently required in order to sensitize the population to the importance of nuclear research for societal impact.

2. The CERN ISOLDE facility: a gateway to fascination

CERN is home to a vast network of accelerators, increasing the energy of protons (that originate from a hydrogen gas bottle) until they reach 99.999 9991% the speed of light. After the initial stage of acceleration, the protons exiting the Proton Synchrotron Booster (PSB) have an energy of 1.4 GeV (91.6% the speed of light). From all the protons that are emitted from the PSB, 50% of them are delivered to ISOLDE (see figure 2) to produce radioactive ion beams. Based on the isotope separation on-line technique (developed in

Denmark at the Niels Bohr Institute in the 1950s [1]), ISOLDE has been producing exotic isotopes since its first experiments in 1967 [2]. These high-energy protons are bombarded onto a thick target (e.g. uranium carbide), producing a vast array of radioactive species which are then ionised. In order to separate the ions of interest (much like finding a needle in haystack), magnets are used to select the radioactive ions that have the correct mass. These fundamental concepts (ionisation, chemical difference, path of a charged particle in a magnetic field), necessary for explaining how ISOLDE works, can be easily grasped by even a young audience [3].

The reactions between the protons and the target material result in quadrillions of nuclear reactions and the build up of radioactivity in the target. The air in the room where the target is irradiated is also activated, and $>7000\text{m}^3\text{ h}^{-1}$ of radioactive air have to be pumped and controlled continuously during the operation [4]. The radiation levels in this area rise well above the safe limits and all actions have to be handled remotely with a series of remote-controlled systems and articulated arms from the KUKA company⁵. In case of an incident, access to the facility for inspection is also impossible for several days and the first investigation is always performed with a remotely controlled Telex robot with cameras⁶. Those robots are key to the safe, day-to-day operation of the facility and their use is found in a variety of other applications, such as along assembly lines in modern manufacturing plants [5].

After selection of the exotic isotope of interest, ISOLDE can deliver these isotopes to a selection of permanent (or ‘travelling’) experiments, that can be easily approached by resident scientists and visitors alike⁷. These setups perform experiments in a wide range of physics disciplines, most notably nuclear-structure physics, nuclear astrophysics, fundamental physics, solid state physics, biophysics and medical applications [6–10]. This allows insight into a variety of topics, such as the nature of the strong force, nuclear properties and reactions in stellar evolution. In some cases, the radioactive beam is not the topic of study, but is used as a tool to

investigate the characteristics of new materials or to support novel medical research. ISOLDE hosts a rich and diverse experimental programme, with close to 50 different experiments scheduled each year between Easter and Thanksgiving, which includes more than 700 users spread across 17 member states⁸ and beyond [11].

The ISOLDE facility welcomes hundreds of visitors each year, allowing them a glimpse inside one of CERN’s oldest facilities⁹. With the goal of educating visitors about the world-leading research that is performed at ISOLDE, and encouraging students to consider nuclear physics in their studies, ISOLDE has opened its doors to thousands of visitors in recent years. As shown in figure 3(a), the number of visitors has been steadily increasing over the past six years, reaching over one thousand visitors in 2016. Figure 3(b) presents the breakdown of the type of visitor that comes to ISOLDE. The vast majority of visitors (nearly 50%) are university students from one of the ISOLDE Collaboration’s member countries. This is followed by a significant fraction (22%) of professional visitors and secondary-school students (14%). In recent years, ISOLDE has become a highlight for the CERN Teachers Programmes, which gives high-school teachers the chance to keep up-to-date with the latest developments in physics, and as such, ISOLDE welcomes more teachers into the facility every year [12]. The breakdown of visitor nationality is presented in figure 3(c), illustrating a wide range of visiting countries. University students from France, Belgium, Sweden, Germany and the UK are especially common, often a result of Physics Society organised CERN trips or connections with a member of the ISOLDE personnel.

Multiple times a year, ISOLDE takes part in tours organised by the CERN press office: visiting dignitaries, often involved in science policy, and heads of state. Figure 4 shows one such visit, where ISOLDE welcomed King Philippe of Belgium and Nobel prize winner Francois Englert on May 21, 2014.

A new addition to the ISOLDE facility is the CERN MEDICIS facility [13]. MEDICIS stands for medical isotopes collected from ISOLDE.

⁵ <http://kuka.com/>

⁶ <http://telerob.com/>

⁷ Access to some parts may be restricted at times to account for safety concerns.

⁸ Belgium, Denmark, Finland, France, Germany, Greece, India, Ireland, Italy, Norway, Poland, Romania, Slovakia, South Africa, Spain, Sweden and the United Kingdom.

⁹ For more information on visiting CERN: <https://visit.cern/>

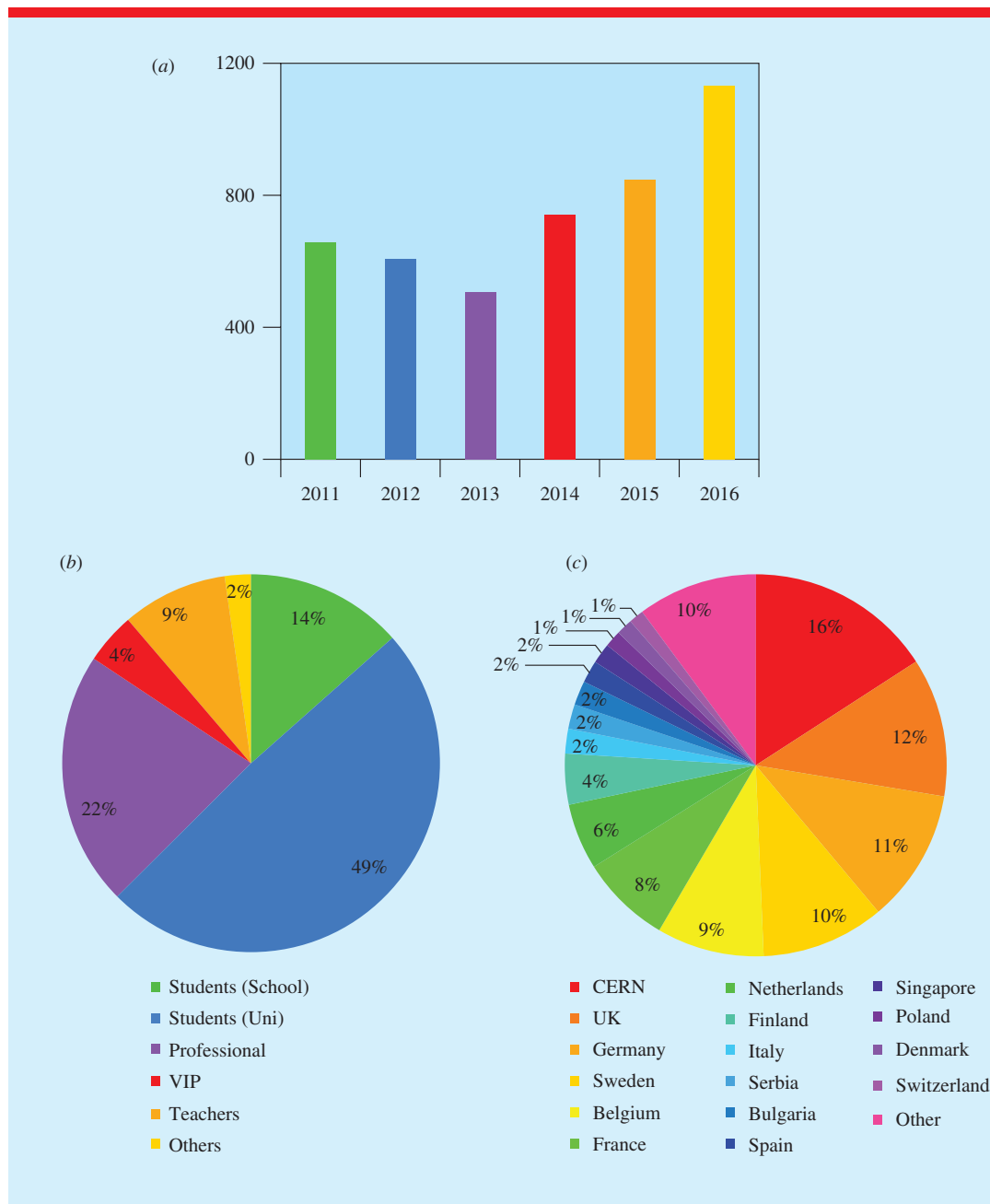


Figure 3. Visitors to the ISOLDE facility. (a) The number of people visiting ISOLDE in the past six years. (b) Breakdown of the type of visitor to ISOLDE in the past five years. (c) Breakdown of the nationality of visitors to ISOLDE.

It is located in a new, parasitic laboratory dedicated to the research of novel medical isotopes. Through the application of the techniques developed and improved over 50 years at ISOLDE, the ISOLDE community aims at providing access

to novel radioisotopes not currently available on the market but which offer great promise for functional imaging and targeted radio-therapy, with the prime interest of answering the need for personalised care in place of the one-size-fits-all



Figure 4. King Philippe of Belgium and Nobel prize winner Francois Englert during a visit on May 21, 2014 to the ISOLDE facility at CERN. Reproduced with permission from CERN.

existing concepts. Such a programme exists at ISOLDE, receiving experimental time twice a year. Unfortunately, such research requires long times of pre-clinical and clinical trials, and these opportunities are too few and far between. By providing these isotopes on a continuous basis, this large limitation can be mitigated and new treatment can be foreseen in the future [10].

The possible impact of such research has attracted a lot of interest and visits to ISOLDE are regularly combined with visits of MEDICIS.

3. The ISOLDE robot project

In this project, we introduce the basic concepts of nuclear physics as they apply to the CERN ISOLDE facility as a means to attract the audience's attention to questions such as fundamental research, nuclear technology and nuclear radiation in general. An interactive aspect is proposed via the working with LEGO® Mindstorms®, based on the use of robotic systems in the harsh environment of the ISOLDE target. The use of LEGO® blocks is a very interactive way of engaging with young and general audiences [14]. LEGO® Mindstorms® themselves have been used before for educative purpose, and their positive impact is promising [15].

The project, as originally proposed, was to address misconceptions about nuclear physics among 14-16-year-olds by inviting ten local schools to participate in a competition to design and build a LEGO® Mindstorms® robot. It was planned that a trained student ambassador would visit each school to give an introductory class workshop on nuclear research and the use of robots to handle nuclear material at ISOLDE, and that the schools would then be loaned a Mindstorms® Education kit. The kits consist of 585 LEGO® elements, a programmable 'brick', and a number of motors, wheels and sensors (which respond to colour, orientation or distance from an obstacle). The sensors and other elements can be connected to the brick in many different combinations, and the brick can then be programmed with the Mindstorm® software application, which uses blocks of code in a similar way to the programming language Scratch.

The intention was that following the introductory workshop, each school would put together a team of up to four students to design and build a robot capable of locating a 'radioactive' LEGO® block, lifting it and transporting it to a given spot. This would be an ongoing project, so probably best suited to after-school STEM clubs, and the student ambassadors would be available virtually to provide

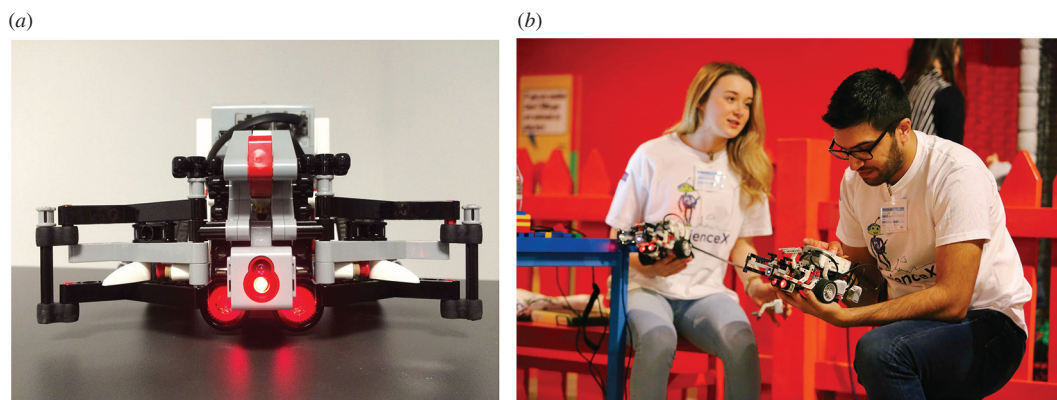


Figure 5. (a) Clarence, the prototype LEGO® Mindstorm® robot used in this project. (b) Undergraduate student ambassadors demonstrating the robots in Legoland Trafford Centre at the ‘ScienceX’ event, April 2016. Used with permission from Emma Scamell.

support. Each team would then attend a competition event on the university campus to test their robots.

The competition element was phased out early in the project due to lack of sign-up from schools—this seemed to be due to teachers’ concerns about the time needed to design and build the robots and/or lack of experience or confidence in using Mindstorms®. It was also considered that in the original proposal, the practical programming side of the project only reached the small team put forward by the school. It was therefore decided to redevelop the whole-class workshops, training undergraduate student ambassadors to deliver an entirely student-led workshop, taking all ten Mindstorms® kits into a classroom and allowing pupils to work in teams of 3–4 to program one of ten identical pre-constructed robots. Asking pupils only to program the robots rather than build one meant that the workshop could be contained into a 1–2h lesson slot, which feedback from teachers had indicated was a priority in fitting these into a school timetable.

The standard robot used in the workshops was designed by one of the undergraduate student ambassadors, modifying one of the base LEGO® Education models with a horizontally closing claw at the front to grip the ‘radioactive material’, see figure 5(a) further information can be found in the supporting information available at (stacks.iop.org/PhysED/52/044004/mmedia). Ten of these were constructed by students, as part of a workshop on campus where they received training in delivering the workshop and engaging with the target age group. Fifteen students ambassadors were trained, and went on to deliver six nuclear-themed

LEGO® robotics workshops for local schools between October 2015 and February 2016.

4. Impact and new activities with the LEGO® mindstorm® kits

The 15 undergraduates who were trained in delivering the workshops completed pre- and post-session questionnaires self-assessing their ability to communicate with secondary school groups, and following the training all reported increased levels of confidence in engaging with young people.

From October 2015 to February 2016 the workshop was delivered six times, to a total of 120 pupils. Feedback was extremely positive, with several schools requesting return visits for other classes or year groups. While originally designed for Year 10 with appropriate modifications to the level of scientific content in the opening presentation this workshop was delivered (to very enthusiastic feedback) to a Year 7 class. A follow-up comment emailed by a parent: ‘(My child) really enjoyed the STEM activity. He had a real excitement about the event both leading up to it and afterwards. I think he particularly enjoyed the fact that they had some independence on their project, with support from the STEM team. He also really appreciated how science can be used in the workplace, how it can be a career and the sort of areas it can impact on’.

An important aspect of the workshops, and one that has been picked up on by teachers, is that they are led by current physics undergraduate students, and that each three-student delivery team has at least one female member. This allows the students

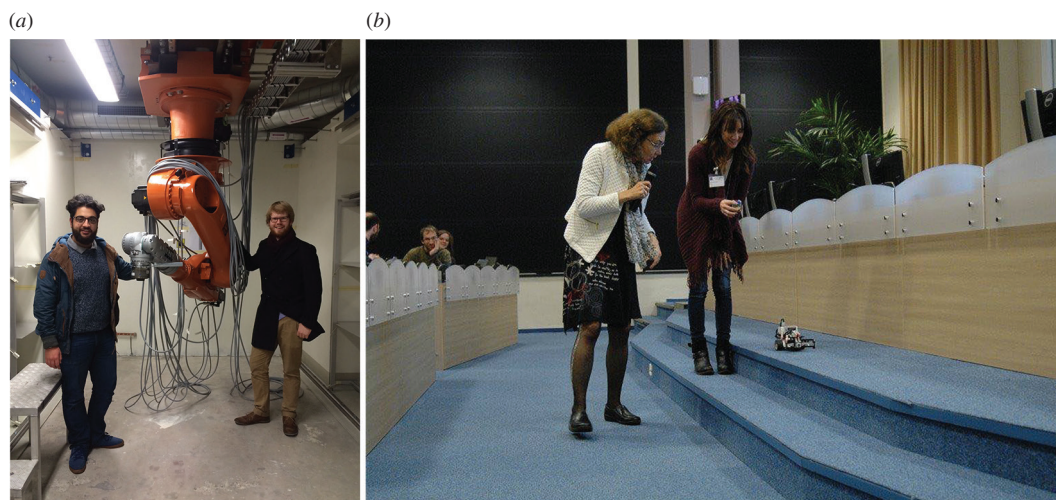


Figure 6. (a) Physics undergraduates Saboor Qureishi (left) and Josh Hayes (right) next to the CERN-MEDICIS Kuka® robot. (b) Maria Jose Garcia Borge (left), ISOLDE Group Leader, and Kara Lynch (right), CERN Fellow and ISOLDE visit coordinator, introducing Clarence to the ISOLDE community at the 2015 ISOLDE Workshop and Users' Meeting.

to act as role models, and to informally talk with pupils during the event about their experience of studying physics, and about physics careers.

In April 2016, student ambassadors took three of the robots to Legoland in Intu Trafford Centre (a shopping centre in Greater Manchester, the second largest by retail size in the UK) as part of the University's ScienceX weekend event, aimed at taking typical university science festival activities to a more general audience, see figure 5(b). An estimated 10000 people were engaged by activities over the two-day event, with around 200 taking part in the LEGO® activity, mostly families with young children. Ironically, given the original remit of the project, we were asked to avoid a nuclear theme in case any customers mistakenly believed the 'radioactive' LEGO® blocks transported by the robots to be genuine radioactive material. The robots, therefore, remained structurally the same but were rebranded as Mars exploration vehicles.

This theme has carried through to a revised workshop, based around the exploration and colonisation of Mars, which in July/August 2016 was delivered to five classes and a total of 145 students between Year 7 and Year 9. It was found that the programming aspect of the workshop was easy to translate to a different context—as with nuclear target handling at ISOLDE, the space travel scenario is an example of using robots to carry out scientific research in extreme environments.

A second revision over summer 2016 simplified the robots, removing the grabbing claw to make it easier for workshop groups to add the various sensors and to allow for a range of different programming challenges. The workshop is currently being offered to schools, and can be delivered as either nuclear or space themed as requested. The success of the programme has ensured its lasting impact in the Greater Manchester area. Its implementation has been expended from the introductory aspect presented here into an intrinsic component of the activities of the University of Manchester Physics Outreach (UMPO)¹⁰. This student-led public engagement body is carrying out the training of new science ambassadors and coordinating the distribution of the workshops in the Greater Manchester area (UK). They can be contacted directly and the material required to reproduce this programme can be obtained via the outreach team of the School of Physics and Astronomy of The University of Manchester¹¹.

The original prototype robot—Clarence, see figure 5(a)—was brought to the annual ISOLDE Workshop and Users' Meeting in December 2015, see figure 6(b) by two of the undergraduate ambassadors (including the designer) presented in figure 6(a) and is now on display in the ISOLDE visitors' centre.

¹⁰ <http://umpo.co.uk/>

¹¹ (<http://physics.manchester.ac.uk/outreach/>)

5. Conclusions

A new project based on LEGO® Mindstorm® has been developed in the Greater Manchester area in order to address the misconceptions and stigma around nuclear physics. This project was built in partnership with CERN ISOLDE, celebrating its 50th anniversary, and CERN MEDICIS, a new facility for supporting nuclear medicine research. This project was originally targeted to 14–15 year old students, but was easily adapted to younger audiences, and even different topics such as Mars exploration.

Several science ambassadors have been trained to deliver workshops in schools as well as at public events, bringing excitement across from a very motivated group. Several hundreds of students have been introduced to a variety of topics from fundamental research in nuclear physics or space exploration, to engineering challenges in harsh environments or the excitement of programming devices. A new generation of science ambassadors are currently being trained to carry on the programme in the Greater Manchester area. Details on this programme are available on demand. A full impact study of this programme can only be realised with a wider number of participants and we look forward to evaluating its large-scale efficacy based on further engagement with the public.

At CERN, the ISOLDE and MEDICIS facilities attract a selected audience with existing ties to nuclear physics. A varied science programme has resulted in generating a lot of interest from different groups and an increase has been seen in the number of visitors.

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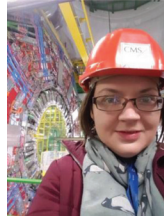
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